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PATENT APPLICATION

Docket No.: D472A

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& Kristine P. Maine

Title: Code Division Multiple Access Enhanced Capacity System

SPECIFICATION

Statement of Government Interest

The invention was made with Government support under contract No. F04701-00-C-0009 by the Department of the Air Force. The Government has certain rights in the invention.

Field of the Invention

The invention relates to the field of code division multiple access communications systems. More particularly the present invention relates to concurrent code formatting of spreading codes in differing formats for use in code division multiple access communications systems for increased channel capacity.

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## Background of the Invention

Code division multiple access (CDMA) communications have been used for some time. Typically, transmitted data is formatted and the spectrum is spread using CDMA spreading codes for communicating CDMA spread spectrum communication signals between a transmitter and a plurality of receivers within a null-to-null communications bandwidth. A transmitted signal includes superimposed spread spectrum signals spread by respective spreading codes for providing code division access to multiple receivers. Differing spreading codes provide signal code division multiplexing for enabling the respective receivers to acquire particular respective communication spread spectrum signals among all of the transmitted spread spectrum signals of the transmitted signal. The CDMA communication systems use a particular digital format to format a data stream prior to spectrum spreading and prior to transmission. The digital format is also applied to the spreading codes prior to spreading formatted data. One such digital format is the nonreturn to zero (NRZ) format. Another format is the Manchester format, also known as biphase-L. In an NRZ CDMA communication system, an NRZ format is used to format separate data streams into NRZ formatted data streams that are then spectrum spread by respective NRZ formatted CDMA spreading codes for transmission to respective receivers. The communication spectrum of an NRZ formatted and spread spectrum CDMA signal is characterized as having a center peak in the communications bandwidth. The communication spectrum is also

1 referred to as a nonsplit spectrum. In a Manchester CDMA  
2 communication system, a Manchester format is used to format  
3 many separate data streams into Manchester formatted data  
4 streams that are then spectrum spread by respective Manchester  
5 formatted CDMA spreading codes for transmission to respective  
6 receivers. The communication spectrum of a Manchester formatted  
7 and spectrum spread CDMA signal is characterized as having a  
8 bandwidth center null of the communications bandwidth. This  
9 spectrum is also known as a split spectrum.

10  
11 Typically, a CDMA system using NRZ formatting has a peak  
12 power spectral density at the center of the frequency band and  
13 is characterized as a nonsplit spectrum signal. A CDMA system  
14 using Manchester code formatting has a power spectral density  
15 null at the center of the frequency band and is characterized  
16 as a split spectrum signal. Another available digital format is  
17 the binary offset carrier format that also provides a split  
18 spectrum of a spread spectrum communication CDMA signal. Yet  
19 another digital format that provides a split spectrum of a  
20 spread spectrum communication CDMA signal is a staggered binary  
21 offset carrier format. The binary offset carrier format, the  
22 staggered binary offset carrier format and the staggered  
23 Manchester format are specific cases of the generalized  
24 Manchester format. Conventional CDMA communication systems  
25 typically use NRZ code formatting. However, CDMA communication  
26 systems can also be implemented using a split spectrum code  
27 format, such as the Manchester code digital format, staggered  
28 Manchester code format, the binary offset carrier digital

1 format and the staggered binary offset carrier digital format.  
2 Manchester formats include all formats formatting an digital  
3 input stream and produces a digital waveform that has one for  
4 more transistions within a symbol time and that are centered  
5 about the center point of the symbol time, with a mean  
6 amplitude value of zero. For examples, Biphase-L has one  
7 centered transistion, staggered Biphase-L has two symmetric  
8 transistions, binary offset carrier has more than one  
9 transistion, and staggered binary offset carrier has more than  
10 two transistions.

11  
12 An NRZ CDMA communication system may, for example, have an  
13 available bandwidth of 200 kHz and have a data rate of 400 bps.  
14 The spreading code chipping rate for the CDMA may be set at 100  
15 kHz so that the null-to-null bandwidth for the spectrum spread  
16 CDMA signal is 200 kHz with a center peak. Channel capacity is  
17 the number of communication channels, that is, spread spectrum  
18 signals, which can be communicated within a given bandwidth.  
19 Using NRZ formatting, the channel capacity is about thirty-  
20 eight at a BER of  $10^{-5}$ . Channel capacity is a valuable resource.  
21 Increasing the channel capacity increases the number of users  
22 that can be served by a CDMA communication system. The NRZ,  
23 Manchester, staggered Manchester, binary offset carrier and  
24 staggered binary offset carrier formatted CDMA communication  
25 systems have limited channel capacities. These and other  
26 disadvantages are solved or reduced using the invention.

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## Summary of the Invention

An object of the invention is to provide increased channel capacity in a code division multiple access communication system.

Another object of the invention is to provide increased channel capacity in a code division multiple access communication system using a plurality of digital formats.

Yet another object of the invention is to provide increased channel capacity in a code division multiple access communication system using spectrum spreading by a pair of digital code formats providing respective communication signal spectra.

Still another object of the invention is to provide increased channel capacity in a code division multiple access communication system using spectrum spreading by a pair of digital code formats respectively providing a communication signal spectrum with a center null and a communication signal spectrum with a center peak.

A further object of the invention is to provide increased channel capacity in a code division multiple access communication system using spectrum spreading with nonreturn to zero spreading code formatting producing a communication signal spectrum with a center peak, and with a generalized Manchester

1 spreading code formatting producing a communication signal  
2 spectrum with a center null.

3  
4 Yet a further object of the invention is to provide  
5 increased channel capacity in a code division multiple access  
6 communication system providing a composite communication  
7 spectrum produced by spectrum spreading with nonreturn to zero  
8 code formatting producing a nonreturn to zero communication  
9 spectrum having a center peak, and with a generalized  
10 Manchester code formatting producing a generalized Manchester  
11 communication spectrum with a center null.

12  
13 The invention is directed to a code division multiple  
14 access communication (CDMA) system using spread spectrum  
15 signaling with at least two different code formats producing  
16 different respective communication signal spectra combined  
17 during transmission as a transmitted communication signal  
18 having a composite spectrum. A first group of data streams is  
19 spectrum spread by a first group of spreading codes formatted  
20 using a first digital code format. A second group of data  
21 streams is spectrum spread by a second group of spreading codes  
22 formatted by a second digital code format. The formatted data  
23 streams are spectrum spread by respective spread codes using  
24 two different code formats. In the preferred form, nonreturn to  
25 zero (NRZ) code formatting and a generalized Manchester code  
26 formatting are used on respective groups of spreading codes for  
27 communicating over respective communication channels. Using NRZ  
28 and a generalized Manchester code formatting, nonsplit and

1 split spectra are produced and superimposed over the  
2 communications bandwidth.

3  
4 In the broad form of the invention, those communications  
5 channels having spreading codes formatted by the first code  
6 format have a first communication signal spectrum, and those  
7 communication channels having spreading codes formatted by the  
8 second code format have a second communication signal spectrum.  
9 The first and second communication signal spectra of the  
10 transmitted communication signal are superimposed during  
11 transmitter modulation to provide a composite communication  
12 signal spectrum of the superimposed first and second  
13 communication signal spectra. Using the two different digital  
14 code formats for formatting the first and second groups of  
15 spreading codes produces two different communication signal  
16 spectra forming the composite communication signal spectrum  
17 that provides for increased channel capacity. These and other  
18 advantages will become more apparent from the following  
19 detailed description of the preferred embodiment.

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## Brief Description of the Drawings

Figure 1 is a block diagram of a dual spectrum code division multiple access (CDMA) transmitter.

Figure 2 is a block diagram of a dual spectrum CDMA receiver.

Figure 3 is a graph of the waveform components of the Manchester formatted signal.

Figure 4 is a graph of the waveform components of the staggered Manchester formatted signal.

Figure 5 is a graph of the power spectral densities of communication spectra using nonreturn to zero (NRZ) formatting and staggered Manchester formatting.

Figure 6 is a graph of the CDMA channel capacity as a function of the signal to noise (SNR) margin.

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## Detailed Description of the Preferred Embodiment

An embodiment of the invention is described with reference to the figures using reference designations as shown in the figures. Referring to Figure 1, a code division multiple access (CDMA) transmitter provides a transmitted communication signal having a dual spectrum over first and second sets of communications channels. The dual spectrum is considered as a composite spectrum having first and second spectra. In the preferred form, the first spectrum is a split spectrum having a center null in the communications bandwidth and the second spectrum is a nonsplit spectrum having a center peak in the communications bandwidth. The communication signal transmitted by the transmitter is a dual spectrum signal communicated over the null-to-null communications bandwidth.

The first set of communication channels communicate a first N1 set of data streams 10. A first data stream of the first set of N1 data streams of user data is clocked through a first shift register 12 for providing first shifted user data. The first shifted user data is nonreturn to zero (NRZ) formatted by a first NRZ data formatter 14 for providing first NRZ formatted data. A first clock generator 16 is used for providing a first data clock for clocking the first data stream through the first shift register 12 and through the NRZ data formatter 14. The clock generator 16 also provides a first code clock to a first CMDA code generator 18 for feeding a spreading code to a NRZ code formatter 20 for providing an NRZ spreading

1 code. The NRZ formatted spreading code modulates the first NRZ  
2 formatted data using a first spreading mixer 22 for providing a  
3 NRZ spread spectrum signal to a first modulator 24.

4  
5 For each of the data streams 10, there is a respective  
6 first shifter 12, first NRZ data formatter 14, first CDMA code  
7 generator 18, first NRZ code formatter 20, first spreading  
8 mixer 22, and first modulator 24, of a first communication  
9 channel in the first set of communication channels. The clock  
10 generator 16 communicates the first data clock signal to all of  
11 the first shifters 12 and all of the first NRZ data formatters  
12 14, and communicates the first code clock signal to all of the  
13 first CDMA code generators 18 and the NRZ code formatters 20,  
14 for synchronized communications.

15  
16 The second set of communication channels communicate a  
17 second N2 set of data streams 26. A second data stream of the  
18 second set of N2 data streams 26 of user data is clocked  
19 through a second shift register 28 for providing second shifted  
20 user data. The second shifted user data is also nonreturn to  
21 zero (NRZ) formatted by a second NRZ data formatter 30 for  
22 providing second NRZ formatted data. A second clock generator  
23 32 is used for generating a second data clock for clocking the  
24 second data stream of the N2 data streams 26 through a second  
25 shift register 28 and through a second NRZ data formatter 30.  
26 The second clock generator 32 also provides a second code clock  
27 to a second CMDA code generator 34 for feeding a second  
28 spreading code to a staggered Manchester code formatter 36 for

1 providing a staggered Manchester formatted spreading code. The  
2 staggered Manchester formatted spreading code modulates the  
3 second NRZ formatted data using a second spreading mixer 38 for  
4 providing a split spectrum spread signal to a second modulator  
5 40.

6  
7 For each of the N2 data streams 26, there is a respective  
8 second shifter 28, second NRZ data formatter 30, second CDMA  
9 code generator 34, staggered Manchester code formatter 36,  
10 second spreading mixer 38, and second modulator 40, of a second  
11 communication channel in the second set of communication  
12 channels. The second clock generator 32 communicates the second  
13 data clock signal to all of the second shifters 28 and to all  
14 of the second NRZ data formatters 30, and communicates a second  
15 code clock signal to all of the second CDMA code generators 34  
16 and to all of the second staggered Manchester code formatters  
17 36, for synchronized communications.

18  
19 The first set of data streams 10 and second set of data  
20 streams 26 are processed through respective communication  
21 channels. However, each of the spreading codes of all of the  
22 channels is different for cochannel isolation. The clock  
23 generators 16 and 32 can be one clock generator for providing  
24 the same clock signals to the first and second sets of  
25 communications channels. Additionally, the first set of data  
26 streams 10 are data formatted and then modulated by NRZ  
27 formatted spreading codes from the first set NRZ code  
28 formatters 20, and the second set of data streams 26 are data

1 formatted and then modulated by a staggered Manchester  
2 formatted spreading codes from the staggered Manchester  
3 formatters 36. The first set of modulators 24 and the second  
4 set of modulators 40 provide respective NRZ spectrum spread  
5 signals and staggered Manchester spectrum spread signals to a  
6 transmitter combiner 42 for combining the NRZ formatted  
7 spectrum spread signals and staggered Manchester spectrum  
8 spread signals into a composite spectrum signals having a dual  
9 spectrum. The NRZ formatted spectrum is a nonsplit spectrum  
10 signal and the staggered Manchester formatted spectrum is a  
11 split spectrum. Hence, the composite spectrum is a composite of  
12 a nonsplit spectrum resulting for NRZ code formatting and a  
13 split spectrum resulting from staggered Manchester code  
14 formatting. The modulators 24 and 40 modulate the spread  
15 spectrum signals by a carrier signal having a carrier  
16 frequency. The composite spread spectrum communication signal  
17 is amplified by a high power amplifier 44 and transmitted as a  
18 dual spectrum communication signal using a transmitter antenna  
19 46.

20  
21 Referring to Figures 1 and 2, and more particularly to  
22 Figure 2, a dual spectrum CDMA receiver receives the split and  
23 nonsplit composite spectrum communication signal as a received  
24 communication signal using a receiver antenna 48. The received  
25 communication signal is amplified by a low noise amplifier 50  
26 and spectrum despread by a despreading mixer 52. A clock  
27 generator 54 is used for providing a receiver clock signal. The  
28 clock generator 54 generates a receiver code clock signal

1 matching the code clock signal generated in the transmitter.  
2 The clock generator 54 also generates data clock signals for  
3 formatting and data detection. In one form of the invention, a  
4 user control 57 is used for selecting the type of code  
5 formatting. In the preferred form, NRZ and staggered Manchester  
6 code formatting is respectively used for formatting the first  
7 and second sets of spreading codes. For a particular channel,  
8 and hence, for a particular CDMA code, the received  
9 communication signal is despread using a spreading code  
10 formatter corresponding to one of the NRZ or staggered  
11 Manchester code formatters 20 or 36 used to spectrum spread one  
12 of the formatted data streams 10 or 26 in the transmitter. The  
13 user control 57 controls the selection of the code format. A  
14 selectable NRZ or staggered Manchester formatter 58 is  
15 selectable to be either an NRZ code formatter or a staggered  
16 Manchester code formatter and is clocked using the code clock  
17 signal from the clock generator 54.

18  
19 A receiver CDMA code generator 56 generates a replica  
20 spreading code for the respective communication channel. The  
21 replica spreading code and the code formatter 58 in the  
22 receiver are identical to the spreading code and the code  
23 formatter used in the transmitter for the same communication  
24 channel. The CDMA code generator 56 generates a CDMA code that  
25 is fed to the receiver code formatter 58 for providing a  
26 formatted code to the despread mixer 52 that then despreads  
27 the communication signal for providing a despread signal. The  
28 despread signal is communicated to a conventional code and

1 carrier tracking loop 60. The code tracking loop 60 provides a  
2 clock error signal to the clock generator 54 for adjusting  
3 clock timing for the despreading code for maintaining code  
4 tracking. The carrier tracking loop 60 provides a carrier  
5 replica to a carrier demodulator 62 for demodulating the  
6 despread communication signal into a carrier demodulated data  
7 stream. The carrier demodulated data stream from carrier  
8 demodulator 62 is fed to a bit synchronizer 64 generating a bit  
9 timing signal that is fed to a data detector 66 for  
10 synchronized clocking of the demodulated data stream into a  
11 replica data stream 68. Bit timing may also be generated from  
12 the tracking loop 60. The data clock signal from the clock  
13 generator 54 is received by the data detector 66 for  
14 synchronizing the replica data stream 68. The replica data  
15 stream 68 is a replica of the data stream 10 or 26 spectrum  
16 spread by the spreading code. In this manner, the receiver can  
17 be used to receive either an NRZ or a staggered Manchester code  
18 formatted CDMA signal of the composite communication signal  
19 respectively having either a nonsplit spectrum or a split  
20 spectrum.

21  
22 The preferred form of the receiver is a code format  
23 selectable receiver. The transmitter can be adapted to change  
24 the code format for a respective channel by feeding a data  
25 stream into either an NRZ or staggered Manchester code  
26 formatted communication channel. However, it should be apparent  
27 that the receiver could be a fixed code format receiver using  
28 either NRZ or staggered Manchester code formatting, but not

1 both, without the use of the user control 57, and without a  
2 selectable formatter 58. The formatter 58 is then either a  
3 fixed NRZ or a fixed staggered Manchester code formatter. In  
4 either case, the data streams can have the same data  
5 formatting, such as NRZ data formatting by NRZ data formatters  
6 14 and 30.

7  
8 Referring to Figures 3 and 4, Manchester and staggered  
9 Manchester code symbol waveforms are respectively shown for  
10 showing that the staggered Manchester code symbol waveform is a  
11 replica of the original Manchester code symbol waveform but  
12 staggered, that is, shifted, in time by a quarter of the code  
13 symbol time  $\tau$ . The staggered Manchester code formatting is done  
14 by staggering the underlying square wave signal by a quarter of  
15 the square wave cycle compared to the underlying square wave of  
16 the Manchester formatted code signal. As a result of this  
17 staggering, the first quarter of the square symbol gets moved  
18 to the last quarter of the square wave symbol as shown in the  
19 Figure 4. It can also be seen from this figure that the  
20 antisymmetry in the waveform shape between the first and the  
21 second half of the code symbol with a Manchester code format is  
22 changed in the case of staggered Manchester code format to a  
23 symmetrical relationship between the two halves of the code  
24 symbol waveform.

25  
26 Referring to all other Figures and more particularly to  
27 Figures 5 and 6, the communication channel signals using NRZ  
28 code formatting or staggered Manchester code formatting have

1 respective nonsplit and split spectra occupying the same null-  
2 to-null communication bandwidth, that may be, for example, 200  
3 kHz with a data rate of 400 bps. The code chipping rate for the  
4 NRZ code formatter in a CDMA system may be a 100 kHz chipping  
5 rate for providing the null-to-null bandwidth for the NRZ code  
6 formatted CDMA signal. With only NRZ code formatted CDMA  
7 signaling, the capacity of fifty CDMA channels is achieved with  
8 an available link margin of 6.0 dB at a BER of  $10^{-5}$ . Under the  
9 same conditions, but with added staggered Manchester code  
10 format signaling at 50.0 kHz, for producing a dual spectrum  
11 CDMA signal, the overall channel capacity is increased. The  
12 communication channel has overlapping nonsplit and split  
13 spectra respectively provided by the NRZ code formatting and  
14 staggered Manchester code formatting. The total channel  
15 capacity is the sum of the NRZ code formatted channels and the  
16 staggered Manchester code formatted channels. The sum total is  
17 improved to sixty nine channels, which is a 38% improvement in  
18 the channel capacity over a conventional CDMA system using only  
19 NRZ code formatting generating a nonsplit spectrum.

20  
21       Power spectral densities for the NRZ and staggered  
22 Manchester code formatted signals, filtered with a 6th order  
23 Butterworth filter have a cutoff of 100 kHz, as is shown in  
24 Figure 5. A 19% to 48% capacity improvement is practicable  
25 using a combination of NRZ code formatting and staggered  
26 Manchester code formatting within a given frequency bandwidth  
27 for link margins of 3-12 dB. With a modest increase in CDMA  
28 system complexity, a CDMA system can obtain increased channel



1 capacity using different code formatters for providing  
2 different overlapping power spectral densities within the null-  
3 to-null communication bandwidth. In the preferred form, NRZ  
4 code formatting generates nonsplit spectra, and, staggered  
5 Manchester code formatting generates split spectra of the dual  
6 spectrum CDMA communication signal.

7  
8       The present invention is directed to a dual spectrum CDMA  
9 communication system using two different code formats for  
10 providing respective spectra overlapping within a communication  
11 bandwidth. The respective spectra share the same bandwidth with  
12 minimal cross interference due to one spectrum having a center  
13 peak and the other spectrum having peaks away from the center,  
14 for effective bandwidth sharing within the same communications  
15 bandwidth. The dual spectrum CDMA communication system offers  
16 increased channel capacity. It should now be apparent that a  
17 mix of transmitters and receivers could operate as part of a  
18 complete communication system communicating both split and  
19 nonsplit spectrum signals. For example, one group of  
20 transmitters or satellites could transmit split spectrum  
21 signals while another group of transmitters or satellites could  
22 transmit nonsplit spectrum signals, all of the signals  
23 communicating within the same CDMA communications bandwidth.  
24 Those skilled in the art can make enhancements, improvements,  
25 and modifications to the invention, and these enhancements,  
26 improvements, and modifications may nonetheless fall within the  
27 spirit and scope of the following claims.

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